

We claim:

1 1. A method for forming a metal pattern in a substrate, the
2 method comprising the steps of:

3 depositing a lower hardmask layer on the substrate, the
4 lower hardmask layer having a dielectric constant less than
5 about 4.5;

6 depositing a middle hardmask layer on the lower hardmask
7 layer;

8 depositing a top hardmask layer on the middle hardmask
9 layer, the top hardmask layer having a thickness less than
10 about 200 Å;

11 forming a first opening in the top hardmask layer in
12 accordance with a first pattern, thereby exposing a portion of
13 the middle hardmask layer;

14 forming a second opening in said portion of the middle
15 hardmask layer in accordance with a second pattern and a
16 corresponding opening in the lower hardmask layer, thereby
17 exposing a portion of the substrate;

18 forming an opening in the substrate;

19 depositing metal in the opening in the substrate; and
20 removing the top hardmask layer.

21 2. A method according to claim 1, wherein the top hardmask
22 layer is of a material selected from the group consisting of
23 refractory metals, refractory metal nitrides, refractory metal
24 alloys, doped amorphous silicon and doped silicon.

25 3. A method according to claim 1, wherein the middle hardmask
26 layer is of a material selected from the group consisting of
27 SiO₂, SiN, SiON and SiOF.

1 4. A method according to claim 1, wherein the lower hardmask
2 layer is of a material selected from the group consisting of
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and
5 amorphous hydrogenated silicon carbide/nitride.

1 5. A method according to claim 1, wherein said step of
2 depositing metal further comprises depositing excess metal
3 overlying the top hardmask layer, and further comprising the
4 step of removing the excess metal by polishing the metal in a
5 chemical-mechanical polishing (CMP) process, a polishing rate
6 of the top hardmask layer being less than a polishing rate of
7 the metal.

1 6. A method according to claim 1, wherein said step of forming
2 the first opening includes depositing a resist layer on the top
3 hardmask layer and subsequently removing the resist layer
4 therefrom, and wherein the middle hardmask layer protects the
5 lower hardmask layer from oxidation during removal of the
6 resist layer.

1 7. A method for forming a metal pattern in a substrate, the
2 substrate having a dielectric constant less than about 4, the
3 method comprising the steps of:

4 depositing a lower hardmask layer on the substrate, the
5 lower hardmask layer having a dielectric constant less than
6 about 4.5;

7 forming a protective layer in a region of the lower
8 hardmask layer adjacent to a top surface thereof;

9 depositing a top hardmask layer on the lower hardmask
10 layer, the top hardmask layer having a thickness less than
11 about 200 Å;

12 forming a first opening in the top hardmask layer in
13 accordance with a first pattern, thereby exposing a portion of
14 the lower hardmask layer;
15 forming a second opening in said portion of the lower
16 hardmask layer in accordance with a second pattern, thereby
17 exposing a portion of the substrate;
18 forming an opening in the substrate;
19 depositing metal in the opening in the substrate; and
20 removing the top hardmask layer.

1 8. A method according to claim 7, wherein the material of said
2 top hardmask layer is selected from the group consisting of
3 refractory metals, refractory metal nitrides, refractory metal
4 alloys, doped amorphous silicon and doped silicon.

5 9. A method according to claim 7, wherein the lower hardmask
6 layer is of a material selected from the group consisting of
7 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
8 silicon oxycarbide, amorphous hydrogenated silicon carbide and
9 amorphous hydrogenated silicon carbide/nitride.

10 10. A method according to claim 7, wherein said step of
11 depositing metal further comprises depositing excess metal
12 overlying the top hardmask layer, and further comprising the
13 step of removing the excess metal by polishing the metal in a
14 chemical-mechanical polishing (CMP) process, a polishing rate
15 of the top hardmask layer being less than a polishing rate of
16 the metal.

1 11. A method according to claim 7, wherein

2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 said step of forming a protective layer comprises exposing
6 the lower hardmask layer to a plasma, thereby forming a
7 protective nitride layer in said region which protects the
8 lower hardmask layer from oxidation during removal of the
9 resist layer.

1 12. A method according to claim 7, wherein

2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 said step of forming a protective layer comprises exposing
6 the lower hardmask layer to a plasma which densifies the lower
7 hardmask layer in said region, so that the protective layer
8 protects the lower hardmask layer from oxidation during removal
9 of the resist layer.

1 13. A method according to claim 7, wherein

2 the lower hardmask layer is deposited under conditions
3 such that the material of the lower hardmask layer has
4 increased density in said region adjacent to the top surface of
5 the lower hardmask layer.

1 14. A method according to claim 7, wherein

2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 the resist layer is removed in a non-oxidizing resist
6 strip process.

1 15. A method according to claim 7, wherein the protective
2 layer has a thickness of approximately 100 Å.

1 16. A method for forming a metal pattern in a substrate, the
2 substrate having a dielectric constant less than about 4, the
3 method comprising the steps of:

4 depositing a lower hardmask layer on the substrate, the
5 lower hardmask layer having a dielectric constant less than
6 about 4.5;

7 depositing a top hardmask layer on the lower layer, the
8 top hardmask layer having a thickness less than about 200 Å;

9 forming a first opening in the top hardmask layer in
10 accordance with a first pattern, thereby exposing a portion of
11 the lower hardmask layer;

12 forming a second opening in said portion of the lower
13 hardmask layer in accordance with a second pattern, thereby
14 exposing a portion of the substrate;

15 forming an opening in the substrate;

16 depositing metal in the opening in the substrate; and

17 removing the top hardmask layer,

18 wherein said step of forming the first opening further
19 comprises depositing a resist layer on the top hardmask layer
20 and subsequently removing the resist layer therefrom, and

21 the resist layer is removed in a non-oxidizing resist
22 strip process.

1 17. A method according to claim 16, wherein the material of
2 said top hardmask layer is selected from the group consisting
3 of refractory metals, refractory metal nitrides, refractory
4 metal alloys, doped amorphous silicon and doped silicon.

1 18. A method according to claim 16, wherein the lower hardmask
2 layer is of a material selected from the group consisting of
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and
5 amorphous hydrogenated silicon carbide/nitride.

1 19. A method according to claim 16, wherein said step of
2 depositing metal further comprises depositing excess metal
3 overlying the top hardmask layer, and further comprising the
4 step of removing the excess metal by polishing the metal in a
5 chemical-mechanical polishing (CMP) process, a polishing rate
6 of the top hardmask layer being less than a polishing rate of
7 the metal.

1 20. A method according to claim 16, wherein the resist strip
2 process is a plasma process with a reducing chemistry.